Seismoacoustic Studies of the Norwegian Sea

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Abstract

The U.S. Navy hydrophone arrays (SOSUS) record seismoacoustic events in a range of frequencies which includes earthquake and explosive sources as well as those relevant to submarine detection, for which they were designed. In the Norwegian Sea we compare detection of seismoacoustic events on SOSUS with seismic detection by the arrays on land in Norway. We also study seismic activity along the spreading centers between Iceland and Svalbard in an attempt to discern any difference in levels of seismicity associated with different sections of the ridge system. Currently, we have assigned archive channels to focus on activity along the Mohns ridge. During March 1995 we recorded many T-phases whose sources have been located along the Mohns ridge using beam steering. Analysis of beamformed data for this continuous one-month period revealed several dozen acoustic events emanating from the southern Mohns ridge and about one third that number from the northern Mohns ridge. Part of this difference is probably due to the choice of beams for the archived data, which emphasizes the southern Mohns ridge, but some of the difference likely reflects the current level of magmatic/tectonic activity. About 10% of the recorded T-phases for this period are preceded by an arrival with greater low frequency content, most likely the P-phase. Approximately two dozen acoustic events were recorded by all channels during the March 95 period suggesting a more distant or larger source, possibly a regional or even teleseismic earthquake. Two of these events correspond to regional events listed in the Center for Monitoring Research (CMR) bulletin, both for which P- and T-phases are observed. The hydroacoustic data have been archived since February 1995 so it is too early to determine systematic patterns in seismic activity or to compile reliable statistics on the relative detection thresholds of the SOSUS system vs the land arrays that can monitor the Norwegian Sea. This work, along with quantitative characterization of the acoustic signals as a function of source parameters, will be the focus of our upcoming investigative year.

1. *Objectives*

The goal of the investigation in the Norwegian Sea is to assess the usefulness of SOSUS as a tool for seismology and to further our understanding of seismoacoustic wave propagation in ocean basins. Analysis of earthquake detection levels and our ability to characterize both natural and manmade seismic sources will determine how reliably the Navy hydrophone arrays can supplement, or even replace, seismometer arrays on land.

Comparison of the number and types of events recorded by the SOSUS arrays vs those detected by the land arrays is a main focus during this second investigative year. This entails systematic analysis of hydrophone data for continuous time periods as well as directed searches for specific events recorded on land. Along with event detections and source locations, we are developing a catalogue of acoustic arrivals. This catalogue will ultimately be used to quantify the relationship between source parameters and T-phase signal character.

The Norwegian Sea offers a unique setting for assessing SOSUS use for seismology due to the existing combination of seismic activity, instrumentation and varied oceanographic conditions (Figure 1). The different seismic sources in the region provide a range of signal types and locations (e.g. Vogt, 1986): large oceanic earthquakes from transform faults along the plate boundary between Iceland and Svalbard; smaller oceanic earthquakes associated with volcanic eruptions along the rifting portion of the plate boundary; mining explosions on land; slope failure events on the continental shelf. Several types of recordings of Norwegian Sea seismic activity are available from instruments whose capabilities dovetail each other: the Global Seismic Network (GSN); the seismometer arrays in Norway and on Spitsbergen; and the SOSUS acoustic arrays.

2. *Research Accomplished*

The link to the Norwegian Sea SOSUS system that is required for data archiving was established in February, 1995, through the efforts of Dr. Clyde Nishimura, our colleague at the Naval Research Laboratory in Washington D.C. Useful data began to accrue immediately for 15 of the 16 channels that the archive system can accommodate. For the most part, the first 6 months of data are of good quality allowing us to address several of our initial goals. We were not able to monitor individual hydrophones due to missing wiring diagrams at the site so our initial plans to devote half the archive channels to single phones was modified. Currently we are monitoring 16 pre-formed beams (processed using the U.S. Navy beamforming parameters) from more than one location. We decided to focus our initial efforts on the Mohns ridge, a known source of frequent, low-level seismic activity, and the Jan Mayen transform fault, along which larger earthquakes are generated (Vogt, 1986; observations from the Norwegian arrays). Therefore, our specific choice of beams to monitor in this initial stage reflects this decision.

The array locations are classified so data must be processed at the secure facility at NRL (the Dual Use Analysis Center was designed to accommodate scientific research using SOSUS data (Nishimura and Conlon, 1994). The archive tapes are sent to NRL at 3-4 week intervals, each tape containing 2-3 days worth of 16-channel data. The sampling rate is well above that required for seismic research since marine mammal research is carried out with the same data. In May 1995, tapes for the first 5 weeks of the archive were available so these data were downloaded and the number and types of acoustic arrivals recorded on the various channels was catalogued for a continuous 36-

day period. Subsequently, the corresponding CMR and QED (U.S. Geological Survey's Quarterly Epicenter Determination) bulletins were consulted in order to assess which acoustic events were likely to be regional or teleseismic arrivals.

Events recorded for the 36-day period can be classified in three categories reflecting source region: southern Mohns ridge; northern Mohns ridge; more distant regional or teleseismic events. The events are only generally located at this stage based on which beams showed a signal, which did not and what the relative amplitude of the arrivals was between beams with signal. For these low frequencies, the beams are quite broad. Almost a hundred T-phases emanating from the southern Mohns ridge were recorded, 11 had a preceding P-phase with short duration and lower frequency content. The T-phases varied in amplitude, spectral content and duration. Just over two dozen T-phases were recorded from the northern Mohns ridge area, only one of which had a clear P-wave preceding it. All channels recorded 28 events, 6 of which were preceded by probable P-wave energy. Based on the available CMR listings for this time period, at least two of these all-channel events correspond to known regional earthquakes: a 4.1 mb on the Kolbeinsey ridge and a 2.3 ML on the Knipovich ridge (+'s in Figure 2). Teleseismic arrivals should be observable (Slack and Purdy, 1995, have observed P-waves from several earthquakes of magnitude 5.5 and greater in SOSUS data from Atlantic and Pacific arrays) so we will return to NRL in August to determine if the arrival times correspond to that predicted for the teleseismic QED events during this, and subsequent, periods. Significant low or band pass filtering is usually required to observe teleseismic arrivals through the background noise that pervades near-seafloor hydrophone data (e.g. Blackman et al., 1995). No filtering of the data was attempted during the initial May analysis visit.

The Center for Monitoring Research has agreed to provide a subscription service so that daily bulletins of seismic activity in the Norwegian Sea are automatically sent to us at IGPP. This information provides a rapid means to check event locations and to define time periods during which the hydrophone data may have recorded foreshocks or aftershocks associated with the main event. There have not been any obvious earthquake swarms detected by the Norwegian arrays since late February, 1995. Two events on the plate boundary north of Svalbard may have been related and two events on the Knipovich ridge may be related (Figure 2). For both sets, the two events occurred within a few minutes of each other. CMR lists about twenty events as occurring in the Norwegian Sea between mid-February and mid-July whereas the QED lists 5 events (Figure 2 has different symbols for the different bulletins). Last year we noted a consistent problem where CMR (then CSS) source locations differed from PDE locations by up to 50 km in this region for the 1990-1992 time period. The 1993 addition of the Spitsbergen array improved the match between CSS and PDE locations significantly. These latest data indicate that the CMR locations now match the QED locations rather well in the Norwegian Sea.

Standard techniques can be used to obtain source parameters from the land array data. In contrast, acoustic T-phases are fairly complex with arrival energy often building over a period of many seconds to a maximum and then decaying for as long as a few minutes. This complexity makes the task of using T-phases to determine source parameters rather difficult so we will initially use the land-derived parameters for co-detected events to develop an understanding of how T-phase character (onset time, frequency content, duration, amplitude) reflects source and propagation path parameters. Using code based on HYPOINVERSE but modified (Bryan and Nishimura, 1995) to account for uncertainties typical of T-phase arrivals, we are working to determine how reliably we can locate and parameterize events that are too small to be detected by the land arrays but that are recorded by the hydrophone arrays.

3. *Plans for the Upcoming Year*

Several upgrades in the archive and recording setup will be necessary for us to achieve our complete set of goals for the project- all are currently possible and, with the cooperation of the Navy and NRL, we expect they can be in place in the near future. The connection for the dead channel should be replaced; the gains should be reset so that high amplitude signals are not clipped; the time stamp in the record header should be verified so that acoustic locations can be accurately compared with seismic locations determined from the land arrays; the wiring diagrams should be located so that we can monitor single hydrophones; and, the clock used for generating a time stamp must be upgraded, preferably using an accurate GPS clock.

Source location using the T-phases is just now being attempted with these data. Much of our efforts in this coming year will be devoted to assessing the accuracy with which we can locate events using the acoustic data. This will entail assessment of pick reliability, appropriateness of the code developed by Bryan and Nishimura for this particular data format (our time resolution is better but the distribution of beams relative to source will vary) and development of modifications optimized for the time/geometry constraints with.which we work.

4. *References*

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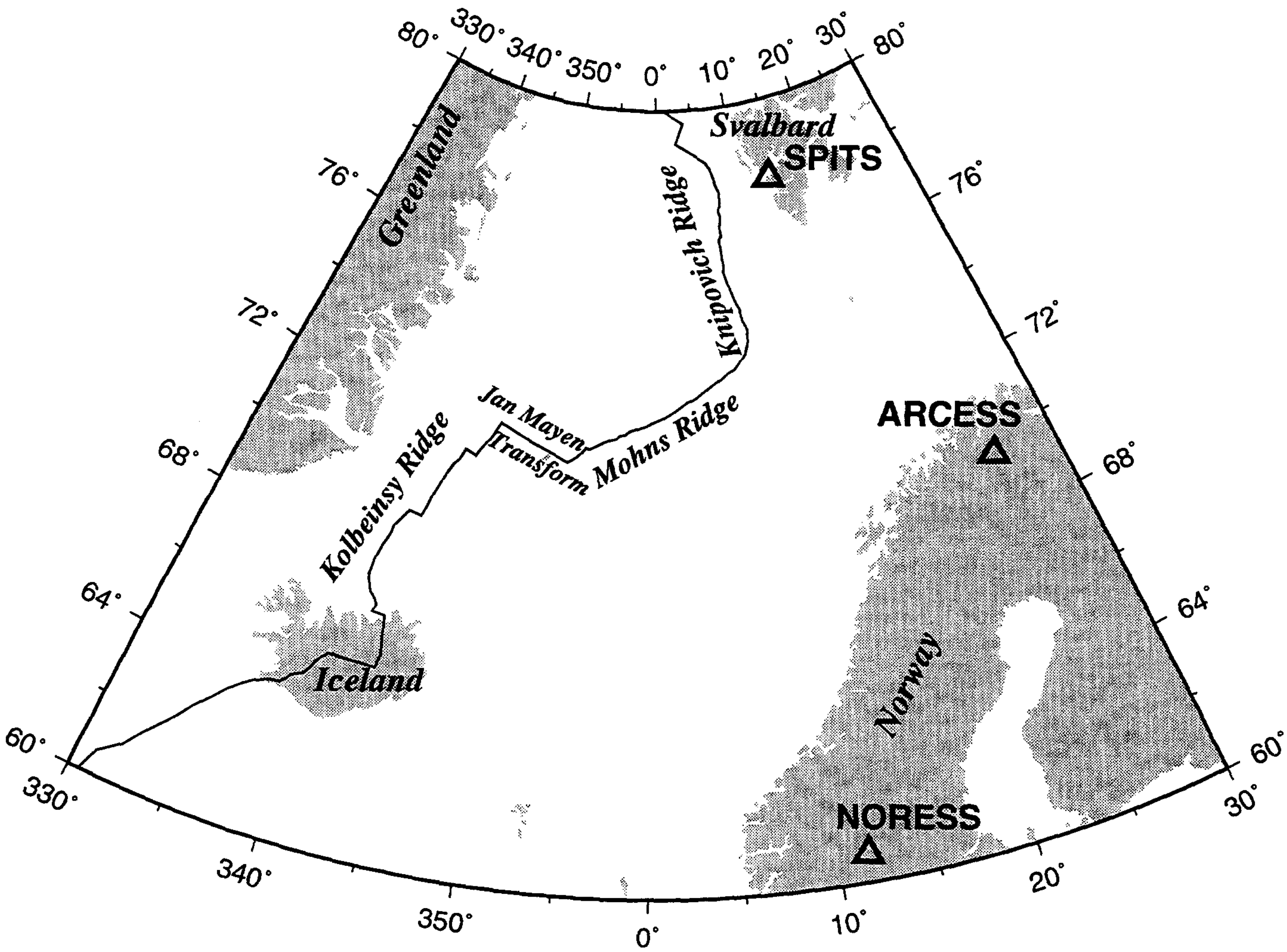

Figure 1. Tectonic setting of Norwegian Sea seismoacoustic study area. Plate boundary is shown by the solid line with spreading centers (Kolbeinsey, Mohns and Knipovich ridges) and transform faults (Jan Mayen) labeled. The Norwegian seismic array locations are indicated by the triangles. 16 channels of beamformed hydrophone data from this area are being archived to characterize acoustic arrivals from local, regional and teleseismic events.

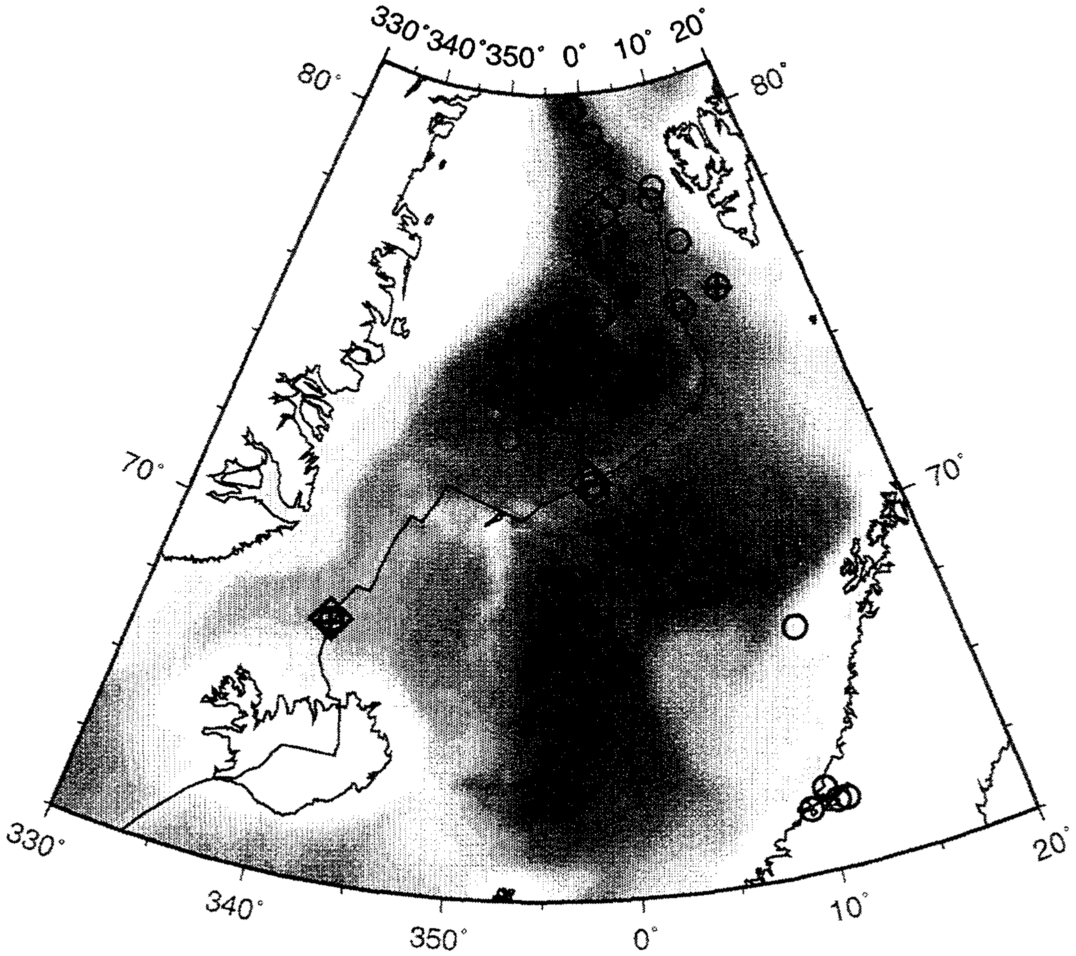

Figure 2. Grayshade of Norwegian Sea bathymetry (darker shades are deepest) and epicenters for earthquakes occurring in the region between mid-February and mid-July 1995. Circles show the location of events listed by CMR; diamonds show locations of events listed in the QED; +'s show the two CMR events that were recorded by SOSUS during March, 1995. One additional March event may have been picked up by SOSUS. The remaining two March CMR events occurred in a region that we were not monitoring with the archived beams.